

Effect of an Oat β -Glucan-Rich Hydrocolloid (C-trim30) on the Rheology and Oil Uptake of Frying Batters

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ABSTRACT: C-trim30, a new β -glucan-rich hydrocolloid containing 32% β -glucan, was obtained by steam jet-cooking and fractionating oat bran concentrates. It was then incorporated into batter formulations to investigate the rheological effects of C-trim30, which were correlated with batter attributes. In steady shear measurements, the use of C-trim30 led to the increase in batter viscosity, while it did not show significant effects on the shear-thinning pattern of batters. Moreover, the increase in the dynamic viscoelastic properties was observed with more contribution to elastic properties because of the high water-holding properties of C-trim30. These rheological characteristics could be correlated with the adhesive properties of batters to a food matrix. In addition, C-trim30 was shown to produce a sample with increased batter pickup, less moisture loss, and reduced oil content. Even, the oil content was reduced by up to 40% when 4% C-trim30 was used in the batter formulations. The combined effects of elevated viscosity, great batter pickup, and reduced moisture loss by the use of C-trim30 contributed synergistically to the reduction of oil content in fried foods.

Keywords: β -glucan, frying, hydrocolloid, oat, oil uptake, rheology

Introduction

Frying with batters has been used as one of the cooking methods for industrial, catering, and domestic uses. In spite of increased health concerns about fat consumption, fried foods given a coating of batter have been enjoyed in large amounts because of their crispy, crackly, and brown crust with the tender and juicy inside. A batter coating enhances the textural, sensory, and visual characteristics of fried foods that are the critical factors in the acceptability of the finished products (Baixauli and others 2003). In addition, the structural properties of coating batters play an important role in oil uptake since frying oil penetrates foods through the crust (Mellema 2003). Therefore, a variety of food materials have been evaluated to reduce oil uptake of fried foods. Rice flour was added to the batter formulation and reduced oil absorption was observed (Shih and Daigle 1999; Dogan and others 2005a; Shih and others 2005). Also, the effects of various starch materials on oil uptake were investigated (Altunakar and others 2004; Salvador and others 2005). In addition, different types of proteins such as soy protein isolate, whey protein isolate, and egg albumen were considered as oil barriers (Dogan and others 2005b).

Recently, a new oat hydrocolloid has been developed as a functional ingredient. Since this product contains elevated levels of β -glucan (32%, db) and less calorie contents (2.6 cal/g), it was designated as C-trim30 with the C for calories (Lee and others 2005). By replacing fat, C-trim30 has been successfully used in food products including chocolate, yogurt, and baked goods (Inglett 2005; Inglett and others 2006). As a hydrocolloid, C-trim30 can play an important role in controlling the texture and rheology of foods (Lee and others

2005). In addition, food products prepared with C-trim30 can have heart healthy label claims approved by FDA because of high content of β -glucan. Thus, the new C-trim30 hydrocolloid and its application can provide beneficial health effects by replacing fat and adding more soluble dietary fibers beyond the traditional functions of hydrocolloids. It would be therefore worthwhile to study its extensive use in other food applications.

In this study, a C-trim30 hydrocolloid was added as a dry ingredient to batter formulations to evaluate its influence on the oil uptake of fried foods. The oil-lowering effect of C-trim30 was also correlated to its water-holding capacity and rheological properties.

Materials and Methods

C-trim30 preparation

A C-trim30 hydrocolloid was obtained according to the method of Lee and others (2005). The oat bran concentrate (100 g, Quaker Oats Co., Chicago, Ill., U.S.A., lot 18608408, item 26629) was suspended in distilled water (1900 mL) and the suspension was sieved through a 400-mesh sieve. After centrifuging the sieve liquid at 1590 \times g for 15 min, the supernatant was mixed with the separated sieve solid. This resulting suspension then passed through a steam jet-cooker that was operated at 65 psi, 285 °F, and 1.2 L/min flow rate. After the steam jet-cooked sample passed through a 200-mesh sieve, the separated liquid was centrifuged at 1590 \times g for 15 min. The supernatant was collected and drum dried, producing a C-trim30 hydrocolloid. The C-trim30 composition was 32.0% β -glucan, 14.4% protein, 2.3% total lipid, 4.8% ash, and 45.3% starch on a dry basis.

Batter preparation

On the basis of the previous method (Lee and Inglett 2006), the batter formula used in this study was composed of 3:5 solid to water ratio. Ninety-six percent all-purpose flour (14% moisture basis,

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General Mills, Minneapolis, Minn., U.S.A.), 3% sodium chloride, and 1% leavening agents (Kraft Foods, Rye Brook, N.Y., U.S.A.) were mixed in a KitchenAid mixer (St. Joseph, Mich., U.S.A.) at speed 1 for 1 min and distilled water was added. They were then mixed at speed 2 for 2 min and after scraping down, the mixing was continued at the same speed for an additional 2 min. For C-trim30-containing samples, the wheat flour was replaced with C-trim30 at levels of 2% and 4%.

Water-holding capacity

The effect of C-trim30 on the water-holding capacity of flours was determined according to the previous procedure with modifications (Ade-Omowaye and others 2003). Flour samples (2 g) with and without C-trim30 were mixed with distilled water (25 g) and vortexed vigorously to make a suspension, which was allowed to stand at room temperature for 30 min. The suspension was then centrifuged at $3000 \times g$ for 15 min, the supernatant was decanted, and the weight of the residue was measured. The water-holding capacity was calculated by the following equation:

$$\text{Water holding capacity (\%)} = \frac{(\text{sample weight after centrifugation} - \text{dry sample weight})}{\text{dry sample weight}} \times 100$$

Two measurements per each sample were made in triplicate.

Rheological measurements

All rheological measurements were performed in a stress-controlled rheometer (AR2000, TA Instruments, New Castle, Del., U.S.A.), which was operated at 25 °C with a parallel plate of 4-cm dia. The steady shear viscosity of batters was measured as a function of shear rates (1 – 500 s^{-1}). In addition, the frequency sweep test was carried out to investigate the effect of C-trim30 on the dynamic viscoelastic properties of batters. Storage modulus (G') and loss modulus (G'') were obtained at frequencies ranging from 0.01 to 10 Hz. A strain of 0.1%, which was within the linear viscoelastic range of all samples, was used for the dynamic experiments. In all measurements, the samples were covered with a thin layer of mineral oil to prevent dehydration during testing.

Batter retention measurements

The effect of C-trim30 on batter-retaining capability (Lee and others 2002) was investigated by using a Texture analyzer (Texture Technologies Co., Scarsdale, N.Y., U.S.A.). A knife blade probe (TA-43, Texture Technologies Co.) was located 3 cm above the surface of batter samples in a rectangular plastic container. It was lowered 5 cm into batter samples at a speed of 5 mm/s, held for 30 s, and returned to its original position. Then, force measurements started immediately, and the force by the retaining batters on the probe was recorded for 200 s.

Batter pickup

To investigate the changes in batter pickup by C-trim30, raw carrots ($4 \times 1 \times 1$ cm) were prepared as food substrates by using a rectangular-shaped mold and knife. Toothpicks were then inserted into the end of the carrots that were dipped into each batter for 10 s. The weight of batter coating adhering to the carrots was measured from the weight decrease of the batter sample after coating. The batter pickup (%) was calculated as follows (Salvador and

others 2005):

$$\text{batter pickup (\%)} = \frac{\text{weight of batter coating}}{\text{weight of an uncoated carrot}} \times 100.$$

Moisture and oil contents of batters

Ten carrots in each batch were fried at 170 °C in a deep fryer (T-FAL, Millville, N.J., U.S.A.) with 2.2 L vegetable oil. After being fried for 3, 6, 9, and 12 min, the samples were withdrawn from the frying oil, kept in a strainer to drain off the excessive oil, and air-cooled at ambient conditions for 30 min. Then the crust was peeled off the carrots and used for the analysis of moisture and oil contents. The moisture content was determined by oven-drying samples at 105 °C until the constant weight was obtained. Also for the analysis of oil content, the fried crust was frozen in liquid nitrogen and ground in a mixer. Then the ground samples of a known weight were transferred to the supercritical CO₂ system (Spe-ed SFE, Applied Separation Inc., Allentown, Pa., U.S.A.) with a 24-mL vessel that was located at 7900 psi and 70 °C. The extraction was carried out at a CO₂ flow rate of 1.0 L/min for 20 min.

Statistical analysis

Batter samples were prepared in triplicate and analysis of variance (ANOVA) was performed to decide significant differences among samples by using the SAS system (SAS Inst. Inc., Cary, N.C., U.S.A.). It was followed by Duncan's multiple range test for mean comparisons in the case of the presence of significant differences.

Results and Discussion

The water-holding capacity of the flours containing a C-trim30 hydrocolloid was investigated. It is shown in Figure 1 that the samples prepared with more C-trim30 had higher water-holding capacity. The C-trim30 hydrocolloid was obtained by subjecting oat bran concentrates to steam jet-cooking, which provides thermal-mechanical shear forces. During this process, starch gelatinization and molecular breakdown of components take place (Lee and Inglett 2006). Also, the fractionation of the steam jet-cooked slurry produces C-trim30 with the high content of β -glucan, consequently giving high hydration properties to C-trim30. Therefore, the incorporation of C-trim30 into the batter formulations gave rise to the significant increase in the ability of batters to retain water.

Figure 2 presents the flow behaviors of frying batters containing C-trim30, showing the viscosity decrease with increasing the rate of shear. While the control showed the lowest viscosity over all shear rates, the incorporation of C-trim30 in batter formulations caused

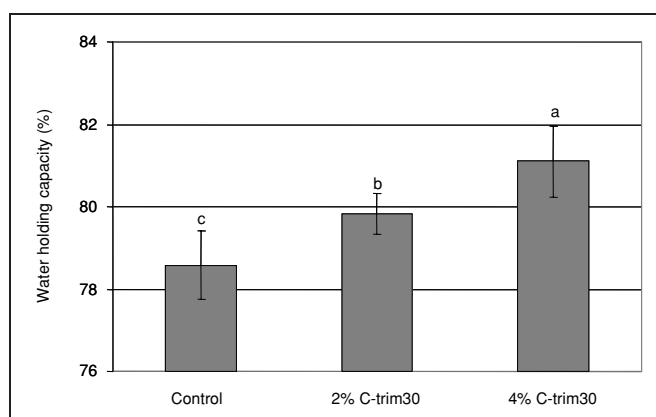


Figure 1 – Effect of C-trim30 on the water-holding capacity of wheat flour (values with the different letter on the bars are significantly different at the 5% level)

the significant increase in batter viscosities. Moreover, the power-law model was employed to describe the flow behaviors, which gave a good fit ($R^2 > 0.99$) to the experimental data as presented in Table 1. In the power law ($\tau = K(\dot{\gamma})^n$), K and n are the consistency index and flow behavior index, respectively. By exhibiting the flow behavior index < 1 , all of the batter samples showed shear thinning behaviors. The shear thinning properties of frying batters have been previously reported in the literature (Dogan and others 2005a; Lee and Inglett 2006). However, the flow index (n) was not a significant function of the variation in the C-trim30 concentration. K , a measure of viscosity, increased in C-trim30-containing batters, showing its dependence on the C-trim30 concentration. It is recognized that batter viscosity depends mainly on the water-binding capacity of the dry ingredients (Dogan and others 2005a). Thus as shown in Figure 1, increased batter viscosity could be due to the enhanced water-holding capacity of C-trim30-containing batters. Furthermore, it was previously shown that C-trim30 in a solution behaves like a random-coil polysaccharide with entanglements (Lee and others 2005), causing the viscosity to increase over concentration. Thus the addition of C-trim30 makes less free water available, consequently increasing the consistency index of batters. Moreover, since the range of shear rate for pumping batters in the food industry is 30 to 500 s^{-1} (Mukprasirt and others 2000), our results would provide useful information to predict the rheological behaviors of batters when operated by a pumping system.

It is recognized that the food-coating performance of batters can be evaluated by their viscosity during processing (Salvador and others 2002). A thin batter with low viscosity may not adhere appropriately to food substrates being coated, impeding the formation of a continuous and crispy crust. Therefore, it is important that a batter has enough viscosity to retain its shape during frying processing. Furthermore, from an industrial point of view, the product yield depends on batter viscosity.

The effect of C-trim30 on the dynamic viscoelastic properties of batters was investigated as a function of frequency (Figure 3). The

Table 1—Effect of C-trim30 on the consistency (K) and flow behavior (n) index of batters

	K	n	R^2
Control	6.03 ± 0.46	0.49 ± 0.01	1.00
2% C-trim30	7.65 ± 0.53	0.54 ± 0.01	0.99
4% C-trim30	13.90 ± 1.46	0.52 ± 0.01	0.99

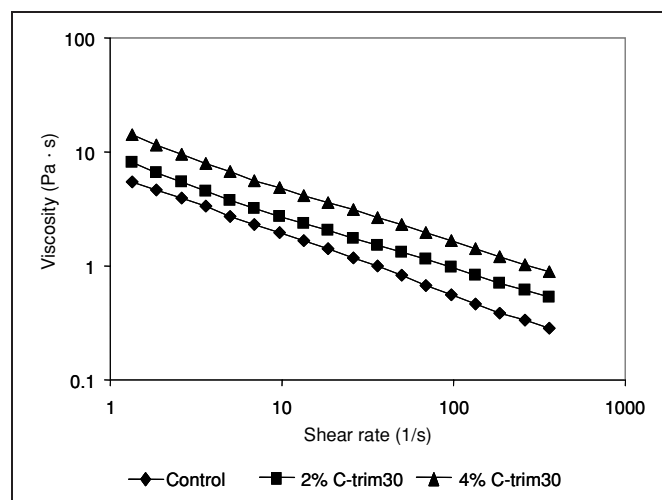


Figure 2—Flow curves of frying batters containing C-trim30 at 25 °C

storage modulus (G') indicates the elastic property of a material and the loss modulus (G'') is involved in its viscous nature. As shown in Figure 3(A), both storage and loss moduli increased with increasing frequency, showing frequency dependence. It appeared that batter samples behaved rheologically like a weak gel as storage moduli were higher than loss moduli over most of the measured frequency range with more frequency dependence of the loss moduli (Lai and Liao 2002). The incorporation of C-trim30 raised also both storage and loss moduli. The storage moduli of batters containing 4% C-trim30 were almost an order of magnitude higher than those of the control, whereas the loss moduli increased by a half order of magnitude. Similarly, within the linear viscoelastic region, the tangent values ($\tan\delta = \text{loss modulus}/\text{storage modulus}$) were significantly affected. As presented in Figure 3(B), the $\tan\delta$ was reduced with more addition of C-trim30, showing more elastic behaviors. It would be attributed to the structural associations of C-trim30 with some batter components, contributing to increased elastic properties. This enhanced elastic feature provides better shape retention during handling and cooking. In addition, it might be related to the crispy texture since the addition of hydrocolloids, which provides more elastic properties, improves the crispiness of fried samples (Akdeniz and others 2006).

Also, the adhesive property of batters to a food matrix was studied. The probe in a texture analyzer was lowered into batter samples,

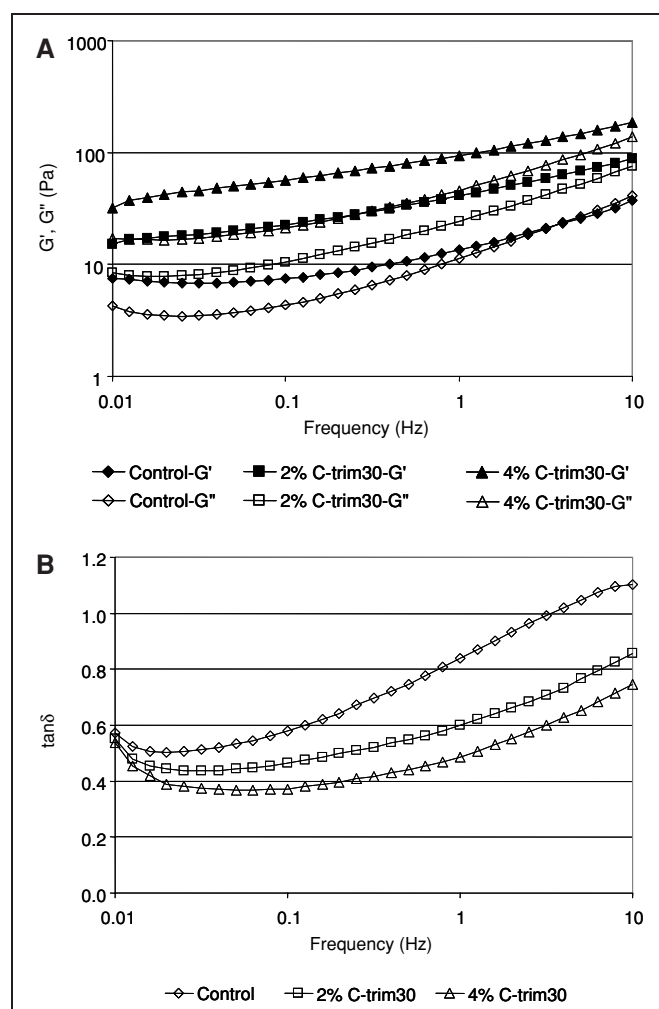


Figure 3—Dynamic viscoelastic properties of C-trim30 batters at 25 °C [a] storage [G'] and loss [G''] modulus, [b] $\tan\delta$

lifted, and then held over time, allowing the batters to drip. Figure 4 shows the amount of batters retained on a probe during a 4-min drip period, which could be indicated by the measured force over time. The batter dripping profile varied distinctly depending on samples. Most of all, the measured force was higher in the batters containing C-trim30 than that of the control. It indicates more batter adhesion on the probe, which could be closely correlated with the batter pickup results shown in Figure 5. In addition, the C-trim30 samples were shown to tenaciously adhere to the food matrix, as compared to the control. Even 4% C-trim30 batters stayed without dripping on the probe for almost 30 s, which was longer by 4 times than the control. After staying bonded on the probe, the batters started to drip down over time. However, the dripping of the control batter stopped within almost 100 s, while the C-trim30 samples continued to drip down during the period tested in this study. Thus, the C-trim30 batters seemed to adhere effectively to a food matrix, resulting in improved batter retention when used in coating systems.

Figure 5 represents the effect of C-trim30 on the batter pickup. The incorporation of C-trim30 had a significant impact on the batter pickup. It is shown that the highest batter pickup was observed in the 4% C-trim30 batter, while the control exhibited the least. Batter pickup depends mainly on batter viscosity, that is, the more viscosity, the higher batter pickup (Akdeniz and others 2005). Therefore, the increase in the batter pickup would be explained by the high viscosity of C-trim30-containing batters as presented in Figure 2.

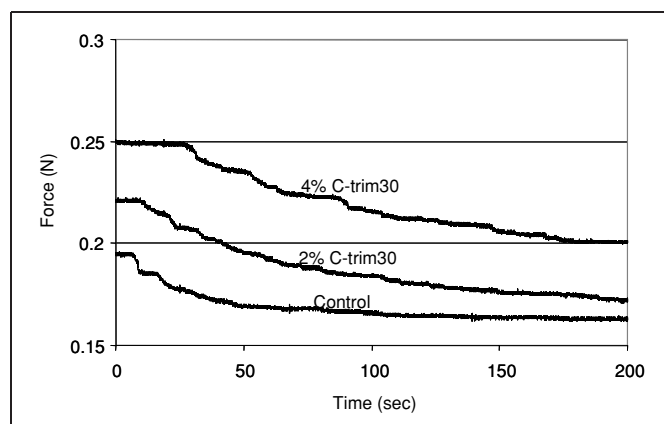


Figure 4 – Changes in batter retention by incorporation of C-trim30 (forces indicate the amount of batters adhering to a probe over time)

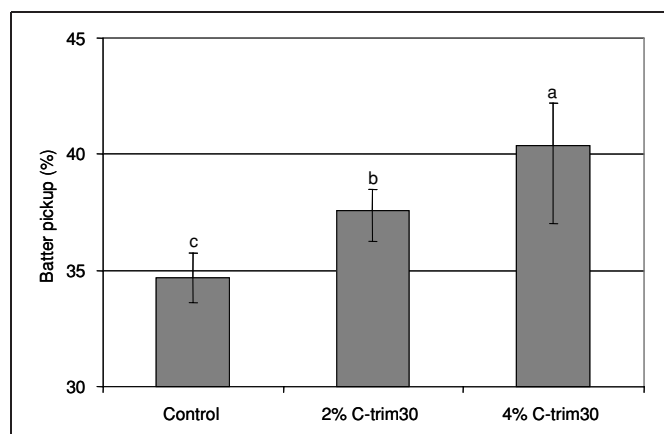


Figure 5 – Changes in batter pickup by incorporation of C-trim30 (values with the different letter on the bars are significantly different at the 5% level)

The moisture content in the fried batters was investigated over frying time as shown in Figure 6. The moisture content was varied when C-trim30 was incorporated into the batter formulations. While the control lost water rapidly during frying, less moisture loss occurred in the samples containing more C-trim30, exhibiting its high water-retaining property. Since all of batter samples were formulated to have the same moisture content, the difference in moisture content among samples after frying would be mainly due to the addition of C-trim30. Therefore, the C-trim30 appeared to be effective in controlling the moisture content of batter coatings during frying.

Figure 7 presents the effect of C-trim30 on the oil uptake of fried batters as a function of frying time. As can be seen, the oil content in all samples increased over frying time. However, the samples containing C-trim30 exhibited significantly less amount of oil than the control. Increasing C-trim30 concentration reduced dramatically the oil absorption. Even the incorporation of 4% C-trim30 provided 40% reduction in the oil content after 12 min of frying, as compared to the control.

When frying a batter-coated food, heat is transferred from the oil to the batter and the water present in the batter evaporates, rapidly leaving the surface in the form of vapor. Since the moisture evaporation leaves pores and voids, which could be filled with oil, more moisture loss would increase the oil uptake of foods during frying. The oil uptake during frying is shown to be directly correlated to the moisture loss of batters; that is, the higher amount of

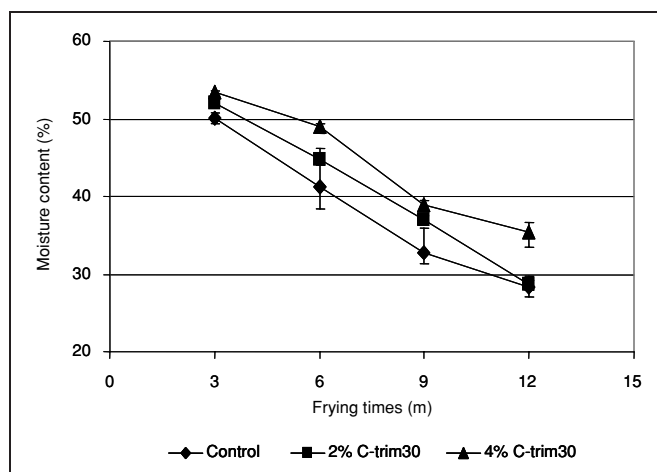


Figure 6 – Effect of C-trim30 on the moisture content of batters

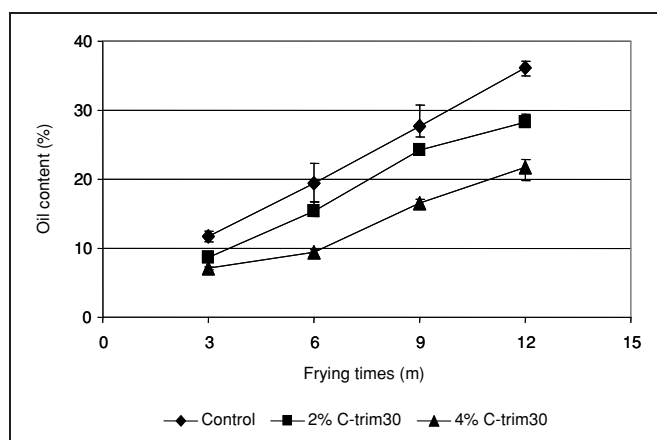


Figure 7 – Effect of C-trim30 on the oil uptake of batters

moisture lost, the higher amount of oil uptake (Mellema 2003; Lee and Inglett 2006). Therefore, the decrease in the oil uptake of C-trim30 batters could be correlated to their enhanced moisture retention as shown in Figure 6. Since high water-holding capacity and viscosity development have a great effect on the reduction of oil uptake (Altunakar and others 2004), the C-trim30 addition improved oil barrier properties of batters. Comprehensively, the high water-holding capacity of C-trim30 caused frying batters to have high viscosity, great batter pickup, and less moisture loss of which combined interactions would contribute synergistically to the low oil uptake of the batters. Moreover, as mentioned earlier, the entangled network formed by C-trim30 might partly help reducing the oil uptake of batters by inhibiting oil penetration during frying.

Conclusions

This study demonstrated the oil-resisting property of C-trim30, a new oat β -glucan-rich hydrocolloid in fried foods coated with batters. When C-trim30 was used in batter formulations, the viscosity and pickup of batters increased and less moisture loss occurred. These combined effects would be responsible for the reduced oil uptake of fried foods containing C-trim30.

Since significant amounts of C-trim30 alter the texture and rheology of foods, enough may not be added to make a label health claim involving the benefits of soluble dietary fibers. However, the use of C-trim30 allows consumers to keep enjoying fried food products with reduced content of oil and calorie, which would be a step in the right direction to healthy diets.

Acknowledgments

Thanks go to Ms. M. P. Kinney for her great support during sample preparations. We also appreciate the technical assistance of Dr. Michael Jackson during supercritical fluid extraction.

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